8:45

IMPORTANCE OF PHASE DURATION IN BIPHASIC - SEQUENTIAL DEFIBRILLATION IN PIGS

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Previous studies have demonstrated an additive advantage of combining biphasic and sequential pulses for defibrillation. Phase duration has been demonstrated to be important for single biphasic shocks. The present study determined the importance of phase duration for biphasic-sequential defibrillation pulses. Triplicate defibrillation thresholds (DFT) were obtained from 8 halothane anesthetized open chest pigs using four orthogonal patch defibrillation electrodes (Medtronic TX 7) sutured to the heart. All animals received each of four different phase durations in random order: a) 3-7, 3-7ms; b) 5-5, 5-5ms; c) 7-3, 7-3ms and d) 10, 10ms. Current and voltage from each pulse were determined by a custom computer program and delivered energy calculated. DFT's for each phase duration averaged (± standard error of the mean): a) 15.3 ± 0.9J; b) 8.3 ± 0.6J; c) 8.2 ± 0.6J and d) 17.7 ± 1.2J, respectively. A significantly lower energy was found with the 5-5, 5-5ms and the 7-3, 7-3ms phase durations ($p<0.05$) compared to either of the other phase durations. The present results suggest that pulse duration is not a major contributor to the advantage of increased number of pulses but rather the phase duration is an important contributor to the decrease in the energy required for defibrillation. Incorporation of a biphasic-sequential pulse with equal or longer followed by shorter phase durations may be important in the design of future generations of implantable defibrillators.

9:00

SODIUM CHANNEL BLOCKADE INHIBITS REFRACTORY PERIOD EXTENSION PRODUCED BY BIPHASIC DEFIBRILLATOR WAVEFORMS IN A COMPUTER MODEL OF THE VENTRICULAR ACTION POTENTIAL

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To determine the role of sodium channel recovery in enhancing refractory period responses produced by biphasic defibrillator waveforms, we modified the Beeler-Reuter computer model of the ventricular action potential to allow a current injection stimulus (S2) during the refractory period (RP) of control (S1) action potentials. The monophasic depolarizing S2 (M) was 10 ms duration. The symmetrical biphasic hyperpolarizing/-depolarizing pulse (B) was 10 ms each pulse and timed so the depolarizing portion corresponded to M S2 coupling interval. Sodium current was allowed to follow its normal time course (+Na) or forced to zero (-Na) before S2 to simulate Na^+ channel blockade. With +Na, S1 threshold (T) was 4 ua/cm^2. At 1.5 X T, maximum response duration difference (B-M) of 78 ms occurred at S1S2=300 ms (end of S1 M RP). Corresponding peak S2 Na^{++} and Ca^{++} currents were larger with B (Ca^{++}=-3.52 vs -1.09 at 300 ms). B-M=0 during S1 phase 4. With -Na, S1 T was 10 ua/cm^2. At 1.5X T (15 ua/cm^2), B-M=-45 at 300 ms, showing improved response for M. Peak Ca^{++} was smaller with B. With +Na at 15 ua/cm^2, B and M durations and currents were similar throughout S1 RP (B-M=6.5 at 300 ms) due to earlier activation by the strong M stimulus.
CONCLUSIONS: 1) Improved sodium channel recovery during the hyperpolarizing prepulse of B allows better excitation channel activation during subsequent low-intensity depolarizing S2. 2) Enhanced S2 responses may increase defibrillation success at low energy by preventing cellular activation by incoming fibrillation wavefronts.

9:15

SYMMETRICAL BIPHASIC DEFIBRILLATOR WAVEFORMS ENHANCE REFRACTORY PERIOD STIMULATION IN THE HUMAN HEART

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During relative refractory period (RRP) stimulation in isolated myocytes, biphasic waveforms enhance responses compared with monophasic waveforms at low stimulus intensities. To determine if this greater efficacy is preserved with catheter stimulation in the human heart, symmetrical biphasic (B) (5.0 ms each pulse) and monophasic waveforms 10 ms (10M) and 20 ms (20M) duration were used to scan ventricular RRP. Ventricular effective refractory period (VERP) was determined at 1.5, 2, and 4 times diastolic threshold (T) in a paired study with 33 patients. Waveforms were delivered following an eight pulse basic train (500 ms cycle length) via distal poles of a standard 6 Fr Quadripolar catheter positioned in the right ventricular apex.
RESULTS: VERP differences between 10M and B were 18.2± 3.4 ms at 1.5*T ($p<0.002$), 29.8±2.7 ms at 2*T ($p<0.001$), and 13.3±3.7 ms at 4*T ($p<0.01$). VERP differences between 20M and B were 6.1±3.9 ms at 1.5*T (p=NS), 17.8±3.0 ms at 2*T ($p<0.001$), and -8.55±2.2 ms at 4*T ($p<0.01$). The maximum paired VERP difference between B and 10M or 20M occurred at 2*T. This difference was significantly reduced (10M) or eliminated (20M) by 4*T.
CONCLUSIONS: 1) In human ventricular myocardium, B stimulates more effectively than M at low shock intensities during the RRP. 2) This difference disappears at high stimulus intensities. 3) More effective stimulation during the RRP may underlie the greater defibrillation efficacy of biphasic waveforms at low shock intensities by prolonging refractoriness to fibrillating wavefronts.

9:30

SHOCK STRENGTH AND TIMING TO PROLONG VENTRICULAR REPOLARIZATION AND REFRACTORINESS

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Prolongation of the ventricular action potential (AP) and refractory period (RP) by electrical shock may play a role in defibrillation. We investigated the shock strength and timing needed for AP and RP prolongation in bathed frog ventricular strips paced at 0.5 Hz (S1). AP duration at the time of the most rapid repolarization was determined with and without (control) a 5 ms rectangular shock (S2) given at S1-S2 intervals that scanned the AP. The S2 potential gradient required to prevent the production of an AP by a local stimulus (S3) 1.5 times diastolic threshold was determined for S3 applied 25, 50, and 100 ms after the end of the control RP (RP prolongation). Control AP duration and RP were 564±92 and 636±103 ms (mean±sd). AP prolongation was significant for S2≥5V/cm. Comparable RP prolongation also occurred.

AP prolongation (ms) by S2 (n=7, *=p<0.05)

S2 gradient (V/cm)	S1-S2 (ms) 100	200	300	400-500
1	-0.8±2.1	0.2±1.9	-1.4±2.0*	0.7±1.6
5	-0.9±2.0	0.1±2.4	3.2±4.5*	19.2*
13	3.1±4.9	12±12*	24±22*	63±52*
28	30±18*	53±28*	71±53*	90±25*
40	183±125*	184±103*	217±114*	267±122

S2 (V/cm) to prolong the RP (n=4)

RP prolongation (ms)	S1-S2 (ms) 100	300	400
25	21.1±6.4	12.4±3.0	7.2±2.8
50	27.3±7.8	19.7±9.9	14.4±10.9
100	32.7±9.6	26.0±9.8	21.9±7.6

The AP and RP are prolonged by S2 potential gradients that are known to occur in the heart during defibrillation. The prolongations increase for stronger S2 and S2 given later in the AP ($p<0.005$). Because of the later effect, the time of repolarization after S2 of a given strength becomes more uniform, supporting the hypothesis that defibrillation shocks decrease the dispersion of refractoriness.